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Potential for Energy Conservation through Air Tightening of New Canadian Houses

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Abstract

The energy savings associated with the air-tightening of new houses equipped with exhaust-only ventilation systems are evaluated in this paper. Potential savings are identified that would result from reducing the leakage area of the envelopes of houses. For most regions of Canada, the air leakage through the envelopes is currently about the same order of magnitude as that needed for air quality. Further tightening would increase the need for supplementary ventilation in most houses. The increased cost of ventilation using exhaust-only fans would offset potential savings due to reduced air leakage with tighter envelopes. It is recommended that this analysis be repeated to evaluate the role of the tighter envelope as a complement to heat recovery ventilation and demand-control ventilation systems.

Introduction

The National Building Code (NBC) [1] currently requires that a 'barrier to air leakage' be incorporated in the envelope of new houses to control interstitial condensation. In the last decade, construction practice has evolved in response to the need for trouble-free envelope design, and, as a result, new houses have been built more airtight [2]. In recognition of this fact, the NBC also requires a mechanical ventilation system capable of producing 0.3 air changes per hour (AC/h), thereby providing a mechanical means of achieving minimum levels of indoor air quality. With only a few regional exceptions, builders have been meeting the intent of the mechanical ventilation provisions of the NBC with exhaust-only fans – typically kitchen and bathroom fan combinations.

Given these developments in NBC requirements and recent trends in house design and construction, how energy-efficient is the current stock with respect to overall air change? As well, are there remaining opportunities for improving the energy efficiency of new houses equipped with exhaust-only systems through more systematic air-tightening of the envelope, without compromising indoor air quality? In this paper, energy budgets associated with various levels of airtightness are examined for 5 locations across Canada, and opportunities for improved energy efficiency are evaluated.

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Approach

The key premise of the analysis developed for this study, and the underlying premise for the NBC provisions on mechanical ventilation, is that minimum levels of fresh air can be supplied by exhaust fans at any point in time when the air change rate due to air leakage is inadequate to sustain air quality. Two scenarios of fan implementation will be discussed.

Given that minimum levels of air quality can be assured by supplementary ventilation, some freedom is introduced in what the appropriate level of airtightness of the envelope should be. A tighter envelope would reduce waste due to uncontrolled ventilation during colder, windy periods but would introduce added energy costs due to additional fan operation during milder, calm conditions. As well, fan control systems that perfectly tailor air change to need are not readily available. Some inefficiencies due to greater reliance on poorly controlled fans would have to be expected. Thus, there appears to be a trade-off between the inefficiencies of uncontrolled air leakage and the inefficiencies of mechanically induced air change. The following method was developed to quantify, by way of examples, how these trade-offs balance out for various levels of envelope airtightness.

A method developed at the National Research Council of Canada [3, 4] for predicting the total hourly air change of a house was implemented in a sensitivity analysis. The method uses the air leakage characteristics of the house and weather parameters to determine the air change rate for each hour of the year. The method also predicts the total air change of the house when fans are operated. This technique was implemented in a computer program to evaluate what the total air change rates with and without ventilation would be over a 7-month heating season. As well, the fan operating times and electricity requirements were accounted for.

Methods

Parameters

An average-sized reference house was defined for this study. Based on a survey of characteristics of 194 houses built in 1989 [5], a house with a volume of 656 m^3 and an envelope surface area of 500 m^2 was specified. Seven values of normalized leakage area (NLA) [defined in 6] were investigated. These varied between 0.9 and 2.7 cm^2/m^2 in increments of 0.3.

The performance evaluations were made for 5 cities: Halifax, Montreal, Toronto, Winnipeg and Vancouver. Electric heating was assumed for Halifax and Montreal, and gas heating was assumed for Toronto, Winnipeg and Vancouver.

Two exhaust fans were specified: a kitchen exhaust fan and a bathroom exhaust fan. Each fan was assigned an installed fan capacity of 30 l/s to meet the 55 l/s required to produce 0.3 AC/h for the reference house.

Scenarios

The key unknown is the control of exhaust fans. The NBC does not call for sophisticated fan controls, and, usually, none are installed. In the absence of a typical control strategy, two scenarios were investigated for the deployment of the exhaust fans.

Case 1. It was assumed that this house is occupied by 3 people 24 h per day, each needing 15 l/s of fresh air, for a total of 45 l/s. This represents about 0.25 AC/h in the reference house. When the model predicts a shortfall in air change for a given hour, the first fan is turned on. If a shortfall still exists, the second fan is turned on over the hour. A minimum operating time of 1 h is assumed once the fans are turned on.

Case 2. Case 2 is similar to case 1, with the exception that 2 occupants are assumed to be out of the house for 9 h during the day. Thus, during daytime hours, only 15 l/s is assumed to be required to meet the air quality needs of the occupant. This would result in an air change rate of just under 0.2 AC/h, averaged over a 24-hour period. The same control strategy as case 1 is assumed.

The above two cases are the first of many examples that could be investigated. Other occupancies, such as a family of 4 with no one home during daytime hours, and other ventilation strategies incorporating demand-control ventilation or heat recovery ventilators have been left for future investigation.

Other Assumptions

The house is assumed to be in a suburban setting, with sheltered surroundings. The fan motors are assumed to require 1.6 W of electricity to exhaust each liter per second of air from the house. No heat recovery is assumed to occur with infiltration, i.e., the dynamic insulation effect is neglected in the energy analysis.

Analysis and Results

Frequency of Occurrence of Air Change Rates

For each city and each envelope airtightness level, the air change rate was evaluated for each hour without the effect of mechanical ventilation. Figures 1 and 2 show example frequency distributions of these rates as a function of outdoor temperature, for NLAs of 2.1 and 1.5 respectively, for the reference house in Winnipeg. It can be seen from figure 1 that the house with an NLA of 2.1 has a natural air change rate of 0.3 AC/h for the largest number of hours. At milder temperatures, when the driving pressures are smaller, the natural air change rates were lower (0.2 AC/h).

Figure 2 shows a similar set of histograms of air change rates for a tighter envelope having an NLA of 1.5. Here, the majority of hours have air change rates below the 0.25 AC/h required in case 1. Supplemental ventilation is

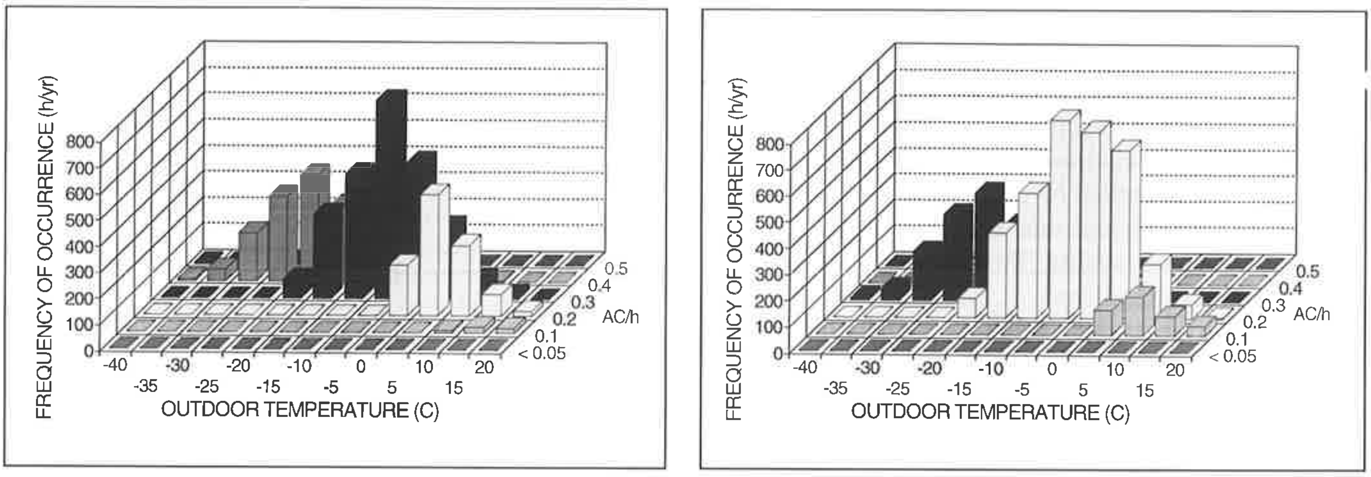

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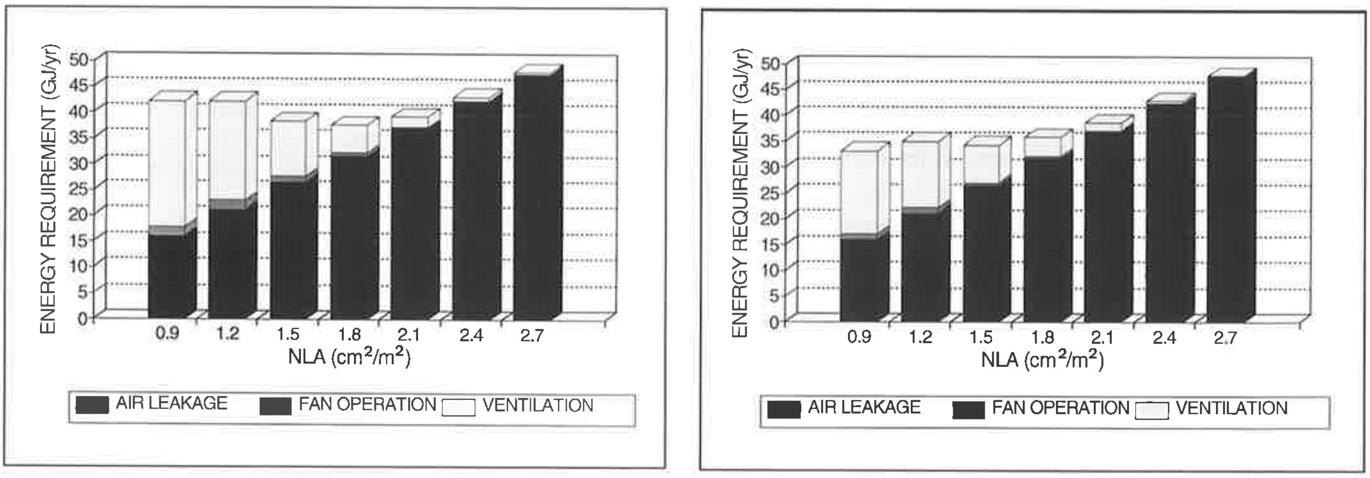
Fig. 1, 2. Distribution of air change rates in Winnipeg as a function of outdoor temperature. **1** NLA = 2.1 (average tightness). **2** NLA = 1.5 (tighter house).



3 4

Fig. 3, 4. Seasonal energy use attributed to air change as a function of NLA (Winnipeg) in case 1 (**3**), with a daytime occupancy of 3 persons, and case 2 (**4**) with 1 person.

required more often, even for colder temperatures. Nevertheless, the bands of excessive air change are almost eliminated.

Energy Impact

For each hour, supplemental ventilation requirements are determined and the impact of mechanical ventilation on the overall air change rate is estimated using a model developed by Shaw [4]. The difference between the air change rate with fans and that without fans is attributed to the operation of fans. The resulting amount is usually less than the total flow through the fans, because fan operation affects the pattern of pressure differences across the envelope. In fact, because of these interactions, it was found that a single 30 l/s fan was rarely sufficient to increase the air change rate up to the desired amount, once the air leakage had fallen below that amount. The interaction between fan exhaust, infiltration and exfiltration contributes to the inefficiency of the ventilation system.

The energy requirements were evaluated for each hour and summed over the heating season for the following three components: air leakage without fans, additional air flow with the fans, and the fan power. Examples of this evaluation are shown for Winnipeg in figures 3 and 4, for

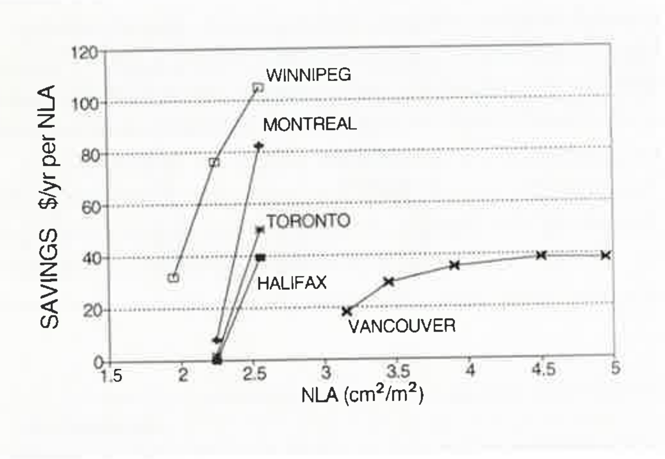


Fig. 5. Predicted savings associated with air-tightening the reference houses in each location, case 1.

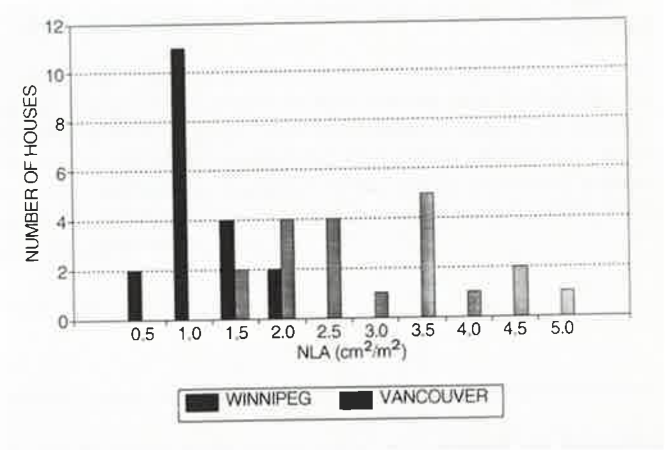


Fig. 6. Distribution of the occurrence of NLAs for houses surveyed in Winnipeg and Vancouver.

cases 1 and 2, respectively. The effect of air leakage (dark portion of the bar) decreases linearly with decreasing NLA. The fans' requirements for electricity increase as the house gets tighter, but this component is relatively small even for the lowest NLA, for which the fans operate continuously. The ventilation component increases dramatically for NLAs of less than 2.1. In fact, since the two fans are of a size to meet the NBC, and 1 fan alone is barely capable of increasing air change rates to the desired level, the greater use of fans with lower NLAs entails an energy penalty due to overventilation, as shown for case 1 in figure 3.

For case 1, an ideal system which could provide exactly 45 l/s continuously would consume 28 GJ over the heating season in Winnipeg. The NLA with the best energy performance shown in figure 3 (NLA = 1.8) has a seasonal total air leakage component that is just above the energy consumption of an ideal system. This NLA features a small inefficiency due to excessive air leakage during cold and windy periods and a small ventilation inefficiency during mild and calm periods: other NLAs feature higher inefficiencies.

Figure 4 shows the seasonal energy requirements for the same range of NLAs in Winnipeg, for case 2. The air leakage components without fans are the same as with case 1; however, ventilation requirements are reduced because air leakage alone can satisfy the daytime requirement of 15 l/s much of the time for envelopes having NLAs of 1.5 or more. Again, the inefficiency associated with the assumed control strategy results in diminished returns at an NLA of less than 1.5.

Energy Costs and Savings

The annual energy requirements such as the ones shown for Winnipeg in figures 3 and 4 were evaluated for the other cities. The functional relationships between total energy and NLA followed similar patterns to those shown for Winnipeg.

The total energy requirement for each NLA and each location were costed using energy rates applicable in 1990 [Energy Mines and Resources Canada, unpubl. data]. The slopes of the total energy cost curve were calculated, yielding the energy cost saving as a function of NLA, as shown in figure 5 for case 1. Case 2 (not shown) differs from case 1 only with slightly higher savings at the lower end of each curve, where mechanical ventilation and the control strategy play more important roles.

Differences in climate and energy cost explain the regional variations shown in figure 5. The Vancouver results stand out as exceptionally low savings, and at much higher NLAs, which is due to the relatively mild and calm climate and low gas prices. Winnipeg, being both cold and windy in winter, shows the highest savings associated with envelope tightening.

The savings potentials indicated in figure 5 apply to the reference house in each location. To estimate the potential savings that might be associated with building new houses to tighter levels, the results of a survey of the airtightness of recently built houses were used [5]. The NLAs of approximately 20 houses were established for each of the cities studied. Almost 40 houses were surveyed in Toronto. The distributions of NLAs are shown in figure 6 for Winnipeg and Vancouver. The NLAs of houses